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Towards resilient flood risk management for Asian coastal cities: Lessons learned from Hong Kong and Singapore

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A B S T R A C T

Many coastal cities are experiencing growing risk to hydrological hazards through the combination of uncontrolled urban development and exposure to natural phenomena linked to climate change, including rising sea levels, intensified storms, and amplified storm surges. This growing risk is particularly acute in Asian coastal mega-cities, many of which have yet to develop adequate adaptation policies to address plausible impacts of climate change. In this analysis, we review how Hong Kong and Singapore, two of the most affluent coastal cities in East Asia, have initiated many flood mitigation strategies policies that have allowed them to reduce the impacts flooding. These strategies, once relying largely on building flood control structures, have now evolved to include holistic flood risk management approaches that include socio-economic factors. Arguably these two success stories provide inspiration for other coastal Asian cities. However, as climate change and uncontrolled development are likely to increase urban flooding in the future, general improvements could be made to improve knowledge transfer: e.g., develop means to work across policy silos and strike compromises between conflicting sectoral responsibilities, and develop long-term integrated strategies using planning tools and practices to address growing risk. While knowledge transfer cannot be direct because of different geographical settings, socio-economic situations, and political situations, we encourage governments to look beyond engineering-based flood control structures as to develop flood governance programs.

1. Introduction

Coastal port cities in Asia have experienced some of the most rapid growth in the world over the last few decades (Hallegatte et al., 2013; Chan et al., 2012). More than 325 million people are now settled along East Asian coasts; and population is expected to triple by 2050 (Fuchs et al., 2011), in part, via migration of workers and investors seeking attractive employment and business opportunities available at the coasts (Seto, 2011; Bailey, 2011). Many of Asian coastal cities are predicted to be vulnerable under climate change (e.g. sea-level rise) (Hanson et al., 2011), thus flood risk will be significantly increasing alongside with rapid growth of socio-economic developments (e.g. greater financial investments and increasing capitals in the flood prone areas) in these cities. On the other hand, these Asian cities are also suffering from an increasing frequency of typhoons, intensive rainstorms and storm surges from the West Pacific (Webster et al., 2005). Evidently, numerous of Asian cities have been impacted by severe floods. For example, cyclone Nargis in 2008 inundated to 75 km inland area close by Yangon, Myanmar, caused more than 140,000 casualties and US$17 billion economic losses (Terry et al., 2012). During July to November 2011 Chao Phraya River catchment flood had inundated parts of Bangkok, as because of the city is located at the river mouth, several districts of Bangkok, especially those bordering Pathum Thani had been flooded severely caused serious economic losses over US$4 billion (BBC, 2011). These examples demonstrated Asian cities,

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particularly cities that locate in coastal areas are highly exposed to several types of floods (e.g. coastal, riverine/fluvial an urban pluvial/surface water/waterlogging), and the consequences and risk is high due to rapidly growing populations and economies. At the same time Asian coastal cities also experience (often anthropogenically induced (e.g. over-extraction of groundwater resources)) land subsidence (Syvitski et al., 2009).

Meanwhile, Hong Kong and Singapore are two important coastal Asian cities that are leading global economic hubs and play influential roles in freight and maritime logistics (Wong et al., 2016, 2017; Zhang et al., 2015; Loo, 2008; Cullinane et al., 2006). Both are wealthy cities, with their per capita gross domestic products among the top 10 in the world (World Bank, 2017). Because of their prosperity, Singapore and Hong Kong have been able to greatly be reduced flood risks, largely through traditional flood mitigation approaches, which they have invested upon heavily in the past (Chui et al., 2006; Chow et al., 2016).

Looking forward, the growing likelihood that climate change will increase flood hazards in many areas of the tropics and subtropics facilitates the need to examine how to improve flood governance. Recently, both Hong Kong and Singapore have incorporated Flood Risk Management (FRM) practices to reduce flood risk, supplementing the traditional approach of relying on engineering-based measures with flexible and holistic approaches that also consider the human dimensions of flood risk (DSD, 2017d,e; PUB, 2013a). Given their recent progress in FRM, Hong Kong and Singapore represent entry points to begin examining how other coastal cities in Asia can develop effective practices for addressing flood risks as they grow and climate change impacts manifest in the form of sea-level rise and increases in storm frequency and intensity.

The objective of this paper is to document and provide a comprehensive review of the FRM progress in both cities. To achieve the aims of this study, we reviewed and analysed the past and current flood management practices in HK and SG from policy documents, scholarly publications and media reports. We also identified some areas for improvements and discussed of how experiences from HK and SG can potentially be useful for other Asian coastal cities.

2. Evolution of flood risk management

Worldwide, the notion of '*flood control*' became popular after World War II in 1950s–1960s, when the norm became reducing flood hazards that might damage agricultural production and compromise food security (Table 1). During the '*flood defence*' phase, which dominated the 1970s to the late 1980s, structural engineering approaches (e.g. seawalls, dykes, embankments, breakwaters and levees) were still commonly built to provide flood protection, but lessons learned from prior large flood events shifted the emphasis to the reduction of flood impacts. As populations and urban economic assets increased, it became increasingly challenging to deliver trustworthy safety standard to protect people and properties in new flood prone areas such as coastal cities. Needed was a paradigm shift away from mitigating the flood impacts using traditional engineering standards-based approaches including levees and dykes (Johnson et al., 2005). Further, the situation that few cities worldwide could afford extensive flood prevention led to the exploration of broader approaches for addressing wider consequences (e.g. social and economic perspectives), rather than only focussing on the single-dimension of flood control.

The realisation of ever-growing flood threats with urbanization, as well as the humanitarian and economical need to address their impacts effectively, facilitated the development of FRM practices, which refer to decisions and actions undertaken to mitigate the remaining risk above flood protection design standards (Plate, 2002). Flood risk management is based on the understanding that risks cannot be removed completely. It is a continuous process of analysis, adjustment and adaptation of policies and actions taken to reduce flood risk (Schanze, 2006). Flood practitioners (e.g. engineers) and stakeholders understand flood risk through model-based assessments to identify the following: (1) clear 'sources' of flood hazards (e.g. rainfall, sea-level, river flows, etc.); (2) 'pathways' by which flood hazards may cause harm (e.g. through a floodplain or coastal zone); and (3) 'receptors' (people, properties and ecosystems) that are at risk (Merz et al., 2010). This approach is in tune with climate adaptation, which is also an interactive process, based on learning and reassessment of the policies in the context with the current state of understanding (Carter et al., 2015).

In some areas, FRMs have been implemented successfully with spatial planning policies (e.g. '*National Plan Policy Frameworks*' in the UK; '*Ruimte voor de Rivier* (*Room for the River*)' in The Netherlands; and '*EU Floods Directives*' for the wider EU) to identify areas at risk of flooding (by developing flood risk maps) and then restrict unsafe developments, or perform better land-use planning (DCLG, 2012; European Union, 2007; Vis et al., 2003). These policies and practices are implemented with consideration of social, economic and environmental impacts. It is increasingly understood that it is impossible to control or defend flooding only by any single approach; flood risk management requires consideration of the wider circumstances and consequences. Both Hong Kong and Singapore have recently adopted FRM techniques to improve their flood management programs. The evolution of this process is explored in the next section.

3. Flood risk in Asian coastal cities: the case of Hong Kong and Singapore

Asian coastal cities already experience a high incidence of extreme events such as typhoons and storm surges (Chan et al., 2012; Fuchs et al., 2011), climate change will worsen flood risks from both landward and seaward directions. Landward influences on flood risk relate to intensive rainfall from storms. The frequency and intensity of storm events in the West Pacific region have significantly increased from the 1970s up to the last decade, a trend that may continue further owing to climate change (Wilby and Keenan, 2012; Hanson et al., 2011). Whilst, there is strong evidence that elevated greenhouse gas concentrations will also contribute to greater intensification of precipitation events. That said, it is expected to significantly increase annual mean river discharge and maximum monthly discharge, with increasing the frequency of rainstorm events in nearly future (Min et al., 2011; Milly et al., 2002).

On the other hand, global sea-level rise is escalating flood risk for low lying coastal areas worldwide, rising seas cause a range of effects that are factors of flood risk, such as coastal erosion and impacts on ecosystem (Nicholls et al., 2014). A global sea-level rise will further challenge the shorelines that combine with the effects from storm surge events (Ericson et al., 2006). That may result in more frequent coastal flooding that sea water overtopping of coastal defences that are previously designed for lower level events. The Western North Pacific Ocean, annual and decadal cycles in the genesis points, migratory paths and maximum intensities of typhoons should be anticipated (Terry and Feng, 2010), which, in turn, influence the likelihood of coastal inundation that may impact along the East Asian coastal cities includes Hong Kong, Singapore and other Asian coastal cities. These findings merge with the detailed review from the previous flood events and consequences from the case of Hong Kong and Singapore as follow in this section.

Geographically, Hong Kong and Singapore both have relatively

Table 1
FRM progress from flood control to defence era to flood risk management era from 1930s to the latest era.

Elements	Flood control/defence era	Flood defence era	Flood risk management era
	1930s–1960s	1970s–1980s	Late 1990s onwards
Risk identification and communications	Focus on local level knowledge transfer based on historical records (e.g. river water levels and groundwater levels) and understanding of the risk, the risk perception was dominated in the agricultural business from floods.	Identifying the risk based on the compliance of engineering standard (e.g. water and tidal water level). For example, focused on return periods and probabilistic understanding of flood risk, but risk was not communicated to all stakeholders and only retained as expert knowledge.	Identifying all possible sources and pathways of flooding including address vulnerability, exposure and hazards. Promoting effective communication of risks, consequences, and uncertainties between all stakeholders, especially recognised the communication of risk to public is important (Porter and Demeritt, 2012)
Measure Options	Mostly focused on structural measures that focused on a single structural option (e.g. building a flood wall on a river reach or a small area) with high priority for engineered agricultural flood control.	Mainly focused on the traditional structural engineering solutions, e.g. channelisation, floodgates, etc., popular practices in the United States (i.e. Mississippi River). Moving towards higher priority for engineered urban flood control.	Mixed approach to combine with non/soft structure and hard engineering measures; practices also looking at the catchment based or coastal management plan as considered the larger spatial scale, e.g. coastal flood management plan in England and Wales (Defra, 2007)
Economic -Efficiency of investment	Ineffective – purposely targeted investment scheme; e.g. in the UK, only can protect an area majorly for agricultural lands (Penning-Roswell et al., 1977)	Mainly focused on defending people and property (industrial, business and residential) from flooding	Effective – economic appraisal adopted (i.e. cost-benefit analysis) to maximise the financial efficiency on FRM practices that whether can be justified by the investments and financial returns
Economic – flood insurance	Not popular or no existing role for insurance for major agricultural assets	Start developing the flood insurance and particularly for the United State (Arnell, 1984), many countries started to explore flood insurance practice as a safety net for householders and businesses affected by flooding.	Available in most developed countries – could be a good recovery practice, governments may layoff burdens on economic risk from flooding; getting more important for individuals and communities, for example in UK, EU, Japan, etc. (Lamond and Penning-Rowsell, 2014), which is a crucial factor to mitigate flood impacts and reducing economic risk from flooding.
Social – participation	Limited involvement from stakeholders and public	Limited involvement and most decisions making process were only restricted to governmental authorities.	Promotes wider participation – involvement with planners, engineers, NGOs and the public Responsibilities on managing flood risk involved with wide range of stakeholders and public.
Social – fairness	Not fair: Example from the UK during land drainage only focused to protect agricultural sector	Started to address the priority of flood protection on national security and welfare	Promote social equality, everybody should have rights to get flood protection (i.e. poors and riches)
Environment – Ecological conservation	Not considered – only adopted engineering measures	Existing systems of environmental values are adequately incorporated into project appraisal techniques on flood engineering project (i.e. integration of Environmental Impact Assessment into site specific project).	Policies such as Room for Rivers in the NL, and MSfW in the UK promoted ecological enhancement and conserve natural wetland and rivers for flood storage; Application of SUDs (and LIDs practices)
Strategic appraisal/ Assessments	Not popular – only looking at the benefits of protecting agricultural lands from flood defence that outweigh considerations of benefits/costs.	The economic benefits/costs of flood defence from a national perspective/policy, most of flood projects have appraised the economic benefits models, but not yet focused on environmental and ecological benefits.	Widely popular – adopted sustainability appraisal or strategic environmental assessment, environmental impact assessment (e.g. EU Floods Directive connect with the EU WFD on addressing ecological issues on water environment)
New Developments control	New developments were not the major issue for the policy at that era	Flood defence structures to protect infrastructures and properties, not much considerations of new developments and flood risk.	More detailed and stringent approaches to assessing flood risk in development planning is required. Flood prone areas should be maintained and restored to fulfil their natural functions for flood storage and discharge to conserve habitats, cultural heritage and the environment (Defra, 2005; European Union, 2003)
Integration with spatial planning	No integration with planning process	No integration with planning process at that era	Yes, spatial planning is an important role - examples from the UK (PPS 25/NFIP), Room for Rivers (NL) (DCLG, 2012; European Union, 2007)
Climate change consideration	Not yet consider climate change issues	Limited adaptation approaches to flood proofing or land raising to address with climate change considerations	Including future scenario (continuous monitoring and modelling climate and other data – demographic), improving resilience (e.g. flood-proofing in public infrastructures in Rotterdam – raingarden (Bethemplein water square)

Table 1 (*continued*)

Elements	Flood control/defence era	Flood defence era	Flood risk management era
	1930s–1960s	1970s–1980s	Late 1990s onwards
			and urban stormwater storage carpark) (Frantzeskaki et al., 2014).
Flood warning	Weak and under-developed, the norm was focused on land drainage and rural flood defence on agricultural premises. Not popular in worldwide, the UK and NL developed the high tide warning after the 1953 flood	Getting more important but the national flood warning system were not existed at this stage	Promote flood preparedness and awareness by flood warning, flood risk mapping, civic education, communication and participation A significant tool for managing flood risk, e.g. UK, USA and EU have been developed this practice (Environment Agency, 2014a,b,c, NOAA, 2014a,b, EU Floods Directive, 2007)
Emergency planning and contingency plan	A local responsibility with national guidance and support, example for the land drainage Act to provide emergency guidance to farms in the UK at 1930s	A wider aspect of the emergency planning and contingency plan, for example the emergency contingency plan was adopted in the regional planning documents in the UK (Penning-Rowsell and Chatterton, 1977)	More significant and proved it is important to reduce flood impacts with individuals and communities throughout the contingency plan from the city council or district authorities, e.g. New York City after Storm Sandy (Rosenzweig and Solecki, 2014; Chan et al., 2014)

Sources: Penning-Rowsell and Chatterton (1977); Johnson et al. (2005); Schanze (2006); Penning-Rowsell et al. (2006); Johnson et al. (2007), etc.

small land areas (HK: 1100 km^2; SG: 720 km^2) and are densely populated (HK: 6700 km^{-1}; SG: 7800 km^{-1}). Most land in Singapore has been heavily urbanised and developed for residential, commercial or industrial purposes (Fig. 1). Thirty percent of the island is at an elevation less than 5 m above sea level. Owing to its hilly nature, only about a quarter of the land in Hong Kong has been developed (Chan et al., 2013a,b). Most development is restricted to low-lying coastal areas such as in NW and E of New Territories, Kowloon and Hong Kong Island (Fig. 2). However, in the spatial plans for post-2030, land reclamation is key for planned urbanization: e.g. with further expansion of Lantau Island and creation of a new business district (East Lantau Metropolis) between it and the Hong Kong Island.

Both cities receive abundant rainfall annually – between 1300 and 3000 mm in HK; and approximately 2300 mm in Singapore (HKO, 2015; MSS, 2017). About 80% of the rain in Hong Kong falls between May and September (HKO, 2015); and tropical cyclones occur from July to September. The climate in Singapore is characterised by two monsoon seasons, the Northeast Monsoon (December to March) and the Southwest Monsoon (June to September), yet there are no distinct wet or dry seasons. Strong wind episodes, particularly during Northeast Monsoon surges, can bring about the largest rainfall events of the year (MSS, 2017). Historically, intense land development in low-lying areas, intense rainfall, weak flood protection measures, and lack of public preparedness made both cities highly vulnerable to floods (Chow et al., 2016; Woo and Wong, 2010).

Singapore have experienced several major floods since the 1950s (Chow et al., 2016). For example, in October 1954, heavy downpour of over 100 mm in 2.5 h caused an approximately 30 cm-deep flood in the city centre where many cars were marooned (Singapore Free Press, 1954). In December 1969, one of the worst floods in Singapore history severed all road and rail links between Singapore and West Malaysia, crippled telephone and electricity systems, killed five people, and resulted in total damages of S$4.3 million, as many of Singapore's low-lying areas were inundated (Chow et al., 2016). The cause was heavy rainfall of 467 mm over a 17-h period, coinciding with a high tide of 3.1 m (PUB, 2013b,c). In December 1978, floods were again attributed to torrential monsoon rains with approximately 512 mm of rain falling in a 24-h period (Chow et al., 2016; Straits Times, 1987). Six people died and about a thousand people were evacuated from their homes as a result. The highly publicised floods of 2010 flash floods on Orchard Road, a 2-

Fig. 1. Singapore's flood prone areas – 1970's vs current (Source: PUB).

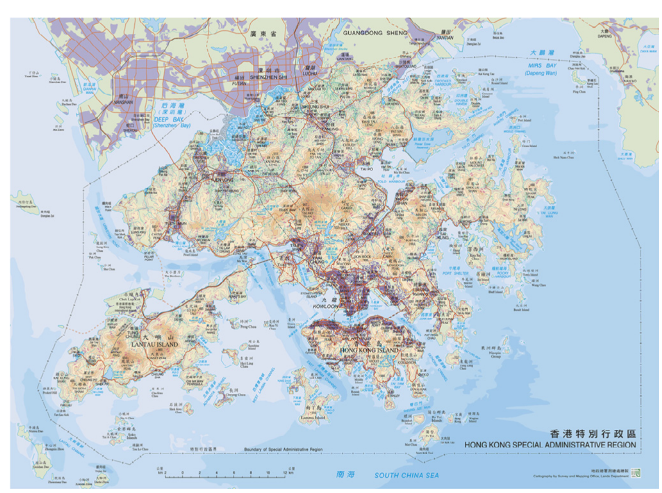

Fig. 2. Hong Kong topography and flood prone area, mostly located on coastal flood prone areas. (Source: Lands Department, Hong Kong Government).

km-long boulevard famously known as a major tourist attraction and as an important retail and entertainment hub, contributed to damages of approximately 23 million SGD from 868 insurance claims from business interruptions, property and motor vehicle damages (PUB, 2012).

Most major floods, both coastal and inland, in Hong Kong typically coincide with tropical cyclone seasons. In September 1962, 230 mm of rain in 24 h brought about by Typhoon Wanda, coupled with a storm surge of +5.34 m above mean sea level, caused substantial coastal flooding in many low-lying prone areas such as North Point and Sheng Wan at Hong Kong Island, Tai Po and Tin Shui Wai in the New Territories. At least 130 deaths were reported; many were injured while some 400 houses and 3500 boats were destroyed (HKO, 2017a; Chan et al., 2013b). In August 1969, floods caused by Typhoon Betty (rainfall of 221 mm in a day) resulted in the evacuation about 2000 people from their homes in the New Territories (HKO, 2017b). Intense rainfall of 416 mm caused by Typhoon Ellen from 24th −25th August 1976 flooded the city centre (HKO, 2017b). Recorded flood levels peaked at 2 m at King's Road in Central. In Sau Mau Ping, Kowloon, water-logged soil resulted in landslides that killed 18 people. Between 20th and 21st May 1989, Typhoon Brenda brought an intensive rain event of 323 mm and caused severe flooding in Kowloon, NW New Territories. Deaths (7) and injuries (119) have been attributed to the flood (HKO, 2017b). A storm surge of +4 m above mean sea level caused by Typhoon Utor on July 6th· 2001 resulted in coastal flooding at Lau Fau Shan at NW New Territories and Tai O town caused one death and destruction of property (HKO, 2017b; Chan et al., 2013b).

More recently, in August 23rd· 2017, Typhoon Hato caused a storm surge of +3.62 m at West Hong Kong Island and East Kowloon, and recorded +3.7 m at Tai O town on Lantau Island (CNN, 2017). Sea water overtopped the sea walls and damaged vehicles and properties at Heng Fa Chuen on Hong Kong Island, also caused other low-lying areas (e.g. Tai O town, East of Hong Kong Island and East of Kowloon) that flooded with a "waist-deep flooding" according to the Hong Kong Observatory (Fig. 3), the HK Government decided to close the hub of financial market − the Hong Kong Stock Market Exchange and the business sectors for a day on 23rd August 2017 to avoid further potential impacts (Kwan et al., 2017), following the resulting floods were estimates to be over 15 million HKD (Weather.com, 2017). This coastal flood event also battered the Pearl River Delta region, caused severe coastal flooding in Guangzhou and Macau. For Macau, this event killed 16 people and injured 153 people in this event (USAtoday.com, 2017; Weather.com, 2017).

That is important to understand the physical impacts of meteorological effects and climate change are only a component of overall flood risk. Risk may also increase owing to anthropogenic and socio-economic factors (landuse changes and management, new developments, investments and capitals, etc.) relating to rapid urbanization and population densities in flood prone areas and zones in these cities. Most of Asian coastal cities are experiencing rapid economic growth. For example, Ningbo in the east coast of China is developing as the largest port in the country (Tang et al., 2015), Shenzhen besides Hong Kong and Guangzhou in the Pearl River Delta is growing to be a high technological hub in the region (Ma, 2012), but unfortunately these two cities have been suffered severe urban floods recently (Ningbo in 2013 after typhoon Fitow and Shenzhen in 2014 by intensive rainstorm during the monsoon season) by climatic and anthropogenic factors. For example, the land drainage system is only equipped up to 1-in-1 to 1-in-10 years in most of Chinese cities (Li et al., 2017; Chan et al., 2014), which evidently implied current flood protection measures are insufficient. Hong Kong and Singapore have been experienced the stage of socio-economic growth in the last few decades, and successfully transformed to be the leading financial hubs in Asia. However, Hong Kong and Singapore have been also suffered from previous floods as illustrated above, their flood management strategies and experiences that mitigating flood risk may contribute towards other Asian coastal cities and will be discussed in next few sections.

4. Flood management practices and progresses in Hong Kong and Singapore

4.1. Traditional flood management practices in Hong Kong and Singapore

Flood management in both Hong Kong and Singapore has typically relied on developing urban drainage systems to handle large volumes of surface runoff generated during storm events in the last few decades. In addition to the construction of new drainage infrastructures, most major natural waterways have been altered via channelization to increase the volumetric discharge capacity. Stream alteration includes the widening, deepening, straightening and concrete-lining of rivers and streams. Presently, there are over 2000 km and 8000 km of these hard-engineered drainage infrastructures in Hong Kong and Singapore, respectively (Chui et al., 2006; PUB, 2014).

Flood alleviation in the two cities has been successful, yet expensive. In Hong Kong, the value of drainage infrastructure projects averaged approximately 13 million HKD annually between 2011 and 2016 (DSD, 2017a). Drainage improvement works including the Drainage Master Plan (DMP), reduced more than 90 flood "blackspots" (from 0.25 to 100 ha flood areas) in 1995, to seven today; these are mainly located in the North district of New Territories low-lying flood-prone area (DSD, 2016). The Drainage Services Department (DSD) is the governed authority for flood protection on inland floods that involves with drainage services and systems (DSD, 2012a,b). Another institution, the Civil Engineering and Development Department (CEDD) is responsible for the coastal land reclamation, also for the design and construction of coastal flood protection infrastructures (e.g. sea walls and breakwaters). According to the Port Works Design Manual Part III (CEDD, 2012a) and IV (CEDD, 2012b), the latest protection standard of coastal land reclamation, seawalls and breakwaters reached 1-in-100 to 200 years return period after 2012, to prevent sea water overtopping in the extreme surges and tidal events. Currently, this protection level on coastal flood protection measures at urban flood prone areas are still more resilient compare to Jakarta (maximum at 1-in-50 years return period) (Budiyono et al., 2015); Bangkok (from 1-in-1 years to 1-in-50 years return period) (Nilubon et al., 2016) and Ho Chi Minh City (up to 1-in-50 years return period) (Duy et al., 2018).

In Singapore, the Public Utility Board received over 190 million SGD per year to fund drainage-related projects from 2010 to 2014 (PUB, 2015). In the 1960s, nearly 13% (6900 ha) of Singapore's main island was susceptible to severe flooding (Lim, 1997). Rapid urbanization following nationhood in 1965 led to an increase the severity of the floods (Chow et al., 2016). In 1972, the Drainage Department was established to alleviate and prevent floods. Through several major drainage projects, the flood prone areas reduced to 3200 ha in the 1970s, and subsequently to 207 ha in the 1990s (Lim, 1997; PUB, 2012). Today, less than 50 ha of Singapore are considered flood prone (PUB, 2012). To combat the effects of sea level rise, PUB raised the minimum land reclamation height from 3 to 4 m in 2011 as a requirement under their "Code of Practice on Surface Water Drainage" (PUB, 2013c). Approximately 70−80% of the shoreline is reinforced with embankments or sea walls to retard storm surges and curb coastal erosion. In addition, the construction of the Marina Barrage in 2008 helped to protect low-lying areas in

Fig. 3. Coastal flood at Tai O town, Hong Kong after Typhoon Hato on 23rd August 2017, the Hong Kong police service helped local victims for emergency evacuation after the flood. (Photo source: Eddie Tse, approved).

the city from the influence of sea tides. Prior to the barrage's completion, low-lying areas in the vicinity were sometimes flooded during extreme high tides, even when there was no rain. The Barrage also functions as a fresh water reservoir to collect rain water for rainstorms (PUB, 2016b).

Both cities have fully learnt from lessons of urban pluvial flooding and established Drainage Master Plans and improved the current major urban drainage system from 1-in-50 years up to 1-in-200 years in Hong Kong (DSD, 2012b) and 1-in-100 years in Singapore (PUB, 2012). Such protection standard of land drainage systems of both HK and SG are ahead of most of Asian coastal cities, such as Bangkok (currently from 1-in-2 to 1-in-10 years) (BMA, 2013); Guangzhou and Shenzhen (both from 1-in1 to 1-in-10 years) (Chan et al., 2014) and Shanghai (from 1-in-1 to 1-in-3 years) (Yin et al., 2016).

There is a strong understanding of the importance of raising adequate ground levels for coastal reclamation projects on new developments (CEDD, 2012a,b; PUB, 2012) and improving coastal infrastructures (e.g. The Marina Barrage at SG (PUB, 2016b); and sea walls and breakwaters at HK (CEDD, 2012a). However, engineered measures are costly and may not provide absolute protection to flooding, as has been shown elsewhere in the world during extreme events – e.g. Hurricane Katrina (New Orleans) in 2005; Hurricane Sandy (New York) in 2013; and more recently, Hurricane Harvey (Texas) and Typhoons Pakhar and Hato (Hong Kong and the Pearl River Delta) in 2017.

Several studies have suggested that cities should avoid over-reliance on traditional, hard-engineered flood protection measures because they may create more risks as both the public and decision-makers become over-reliant or place excessive trust in these infrastructures, while paying comparatively less attention to flood preparedness and awareness as well as the preparation of flood relief emergency plans (cf. Newell and Wasson, 2002; Ziegler et al., 2012a,b; Birkholz et al., 2014). An example occurred in Hong Kong, where the protection level of sea walls and breakwaters is 1-in-200 years in urban coastal residential and commercial areas (CEDD, 2012a), yet flooding still occurred following storm surges during Typhoon Hato in August 2017.

Despite significant progress in drainage improvement, contemporary flood events still occur in both Hong Kong and Singapore and contribute to substantial economic damages and harm (Table 2). An intense storm event in Hong Kong in 2010 (184 mm in 24 h), resulted in flash floods in Tai Po (Northern New Territories) causing three deaths (Chan et al. 2013a, 2014). In contrast, in 2008 and 2009, the town of Tai O was inundated by sea water due to storm surges, as the sea-level suddenly increased to 2 m above normal mean tidal level (HKO, 2013).

According to the Hong Kong Observatory, the mean sea level in the Victoria Harbour from 1954 to 2016 has risen about 15.5 cm (avg. rate about 31 mm per decade) (HKO, 2017e) (Fig. 4). The IPCC AR5 report projected further rise of the global meal sea level about 0.61 m under RCP2.6 or about 0.98 m under RCP8.5 by 2100 (IPCC, 2013). Coastal floods would become more frequent because of the combine effects from a projected sea-level rise and storm surges if the current coastal flood protection level remains unchanged.

In Singapore, the main sea level in the Straits of Singapore has also increased at the rate of 1.2 mm–1.7 mm annually from 1975 to 2009. Otherwise, the annual rainfall is increasing from 2192 mm to 2727 mm in the period of 1975–2009, the rainfall pattern has become more intense in recent years (NCCS, 2017). Reports of flood frequency have significantly increased post-2000 relative to those in the 1980/90s period (Chow et al., 2016). However, these events are typically flash floods that coincide with localised and intense storms. For example, the 2010 Orchard Road was brought about by two consecutive bursts of heavy rainfall amounting to the total of 100 mm in 2 h (PUB, 2012). Another Orchard Road flash flood

Table 2
Recent major flood impacts in Hong Kong and Singapore after 2008

Location	Year	Date	Flood locations	Causes	Impacts	Sources
Hong Kong	2008	25 June	Repulse Bay, Tuen Mun and Lantau Island	Intensive rainstorms enhanced by Typhoon Fengshen (magnitude – 247.1 mm in 24 h)	Surface water flooding occurred and flooded 38 various locations in Hong Kong and caused 17 people injured	HKO (2013) Storm Surge Records in Hong Kong during the Passage of Tropical Cyclones - Database record since 1949.
Hong Kong	2008	24 Sep	Tai O, Cheung Chau, Discovery Bay, Peng Chau, Tuen Mun, Sham Tseng, Sai Kung and Lei Yue Mun	Coastal flooding occurred by +4.91 mean sea level (MSL) plus 43.7 mm in 24 h rainfall	Coastal and surface flooding occurred and flooded over 50 houses, caused some minor injured in Tai O town	Chan et al. (2013b) Coastal Flood-Risk Management Practice in Tai O, a Town in Hong Kong. Environmental Practice, 15, 1–19.
Hong Kong	2009	12 Sep	Tai O and other 8 locations were flooded in New Territories	Coastal flooding occurred by +4.38 MSL plus 50 mm in 24 h rainfall	Over 40 houses were flooded in Tai O town, no injuries and casualties	Chan et al. (2013b) Coastal Flood-Risk Management Practice in Tai O, a Town in Hong Kong. Environmental Practice, 15, 1–19.
Hong Kong	2010	22 July	Northern New Territories	Fluvial flash flooding from hilly areas by intensive rainfall at 184.2 mm in 24 h	44 locations were flooded in Northern New Territories, caused 3 deaths (all drowned) and 10 injured in Tai Po	Chan et al. (2013a). Appraising sustainable flood risk management in the Pearl River Delta's coastal megacities: a case study of Hong Kong, China. Water and Climate Change 4, 390–409.
Singapore	2010	16 June	Bukit Timah, Orchard Road (e.g. Lucky Plaza, Liat Towers, Tong Building and Delfi Orchard)	Intensive rainstorms (magnitude – 100 mm in 2 h)	Surface water flooding occurred and flooded the basement of commercial buildings. Retail shops were inundated	National Environment Agency (2014, April 25) Annual weather review 2011. Retrieved from NEA website: http://app2.nea.gov.sg/training-knowledge-hub/publications/annual-weather-review-2011
	2011	23 Dec	Orchard Road	About 153 mm of rain fell over Orchard Road between 2 p.m. and 5 p.m. that day.	Surface water flooding generated by that torrential rain and inundated cars and shops.	Flash floods hit Liat Towers and other parts of Orchard Road. (December 23, 2011). AsiaOne. Retrieved from http://www.asiaone.com/News/Latest+News/Singapore/Story/A1Story20111223-317945.html
	2012	5 May	Central and North Singapore	68.6 mm/0.5 h (0.2 mm/3 h)	Flood depth 0.25m	Chow et al. (2016)
	2013	5 Sep	West Part of Singapore – commonwealth area	Morning thunderstorm	Widespread surface water floods in west part of Singapore, caused severe traffic trams on the Ayer Rajah Expressway.	Ngiau D (2013) Fiash floods hit several areas in western Singapore (http://www.todayonline.com/singapore/flash-floods-several-areas-western-singapore) and Chow et al. (2016)
	2014	29 July	Orchard Road and CBD (Mackenzie Road)	Heavy rainfall (95.4 mm in 2 h)	Surface water flooding occurred and inundated main roads and traffic jam	Sim W (2014) Heavy rain causes flash floods in Singapore (http://www.straitstimes.com/singapore/environment/heavy-rain-causes-flash-floods-in-singapore)

occurred the following year as a result of 124 mm of rainfall in December 2011, of which, more than half occurred within 30 min (Fig. 5). As a result, urban surface flood occurred and inundated the business district (PUB, 2012). Lately, during January 8th' 2018, an intensive rainstorm with about 118.8 mm was recorded within 4 h during that morning, which was about half of Singapore's average monthly rainfall in January, urban surface flood inundated nine different locations in Eastern Singapore (Channel News Asia, 2018). These intensive rainstorms enhanced urban pluvial or surface water flooding are expected to be more frequent according to IPCC and HKO (IPCC, 2013; HKO, 2017e) (Fig. 6).

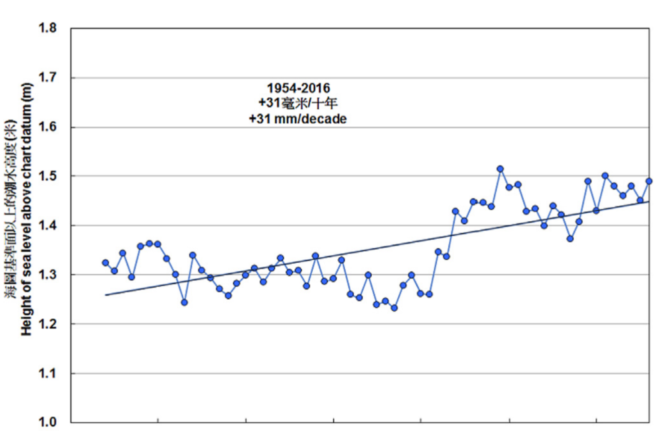

Fig. 4. Annual mean sea level at Victoria Harbour (1954–2016). Source (HKO, 2017e).

While the nature of flooding in both Singapore and Hong Kong have been changing over time through the competing processes of urban development and implementation of flood control measures (Chow et al., 2016; discussed below), both cities remain vulnerable to various types of floods. Compounded by the effects of projected increase in precipitation and sea-level rise because of climate change, the impacts of future flood events in both cities may potentially be economically significant (IPCC, 2013), despite the flood control measures taken to date. Chow et al. (2016) note that "Singapore presently has low vulnerability to floods vis-a-vis other regional cities largely due to holistic flood management" (via consistent and successful infrastructural development, widespread flood monitoring, and effective advisory platforms); however, "future vulnerabilities may increase from stresses arising from physical exposure to climate change and from demographic sensitivity via rapid population growth". In recognition of these threats, flood governance in both cities is an evolving process.

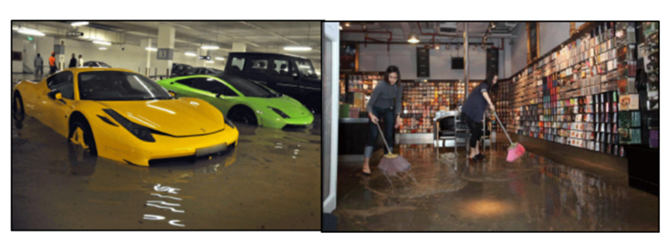

Fig. 5. Flood impact in Orchard Road Business district on 23 Dec 2011 after the intensive rainstorm. Source: (The New Paper, approved).

4.2. FRM frameworks in Hong Kong and Singapore

To address lingering vulnerability to floods, both Hong Kong and Singapore have adopted various FRM measures to flood control. In some instances, this process began before the turn of the century. These measures include the following (discussed below): (1) Basin-wide planning; (2) Enhancing community preparedness; and (3) Meshing sustainability and flood control goals.

4.2.1. Basin-wide planning

Hong Kong has implemented Outline Zoning Plans (OZPs) under the Town Planning Ordinance (TPO) that was amended in 1991 (TPB, 2008) and Drainage Impact Assessments (DIA) in 2010 (DSD, 2010). Developments that require a change in land use specified in the OZPs or other government development plans must seek approval from the Town Planning Board. If a project significantly affects the drainage situation, the developer (or any private sector projects) will be required to conduct a DIA to demonstrate that, with proposed stormwater drainage mitigation measures, the flooding risk to the area concerned will not increase.

In 1994, the Hong Kong Government enacted the Land Drainage Ordinance (LDO) for the DSD to gain access into private land to perform maintenance of watercourses located therein (e.g. river channels). Previously, the Government experienced difficulties in obtaining consent from land-owners to gain access to private lands. The legislated LDO is helpful for managing five drainage basins located in the North district of New Territories, for example, by allowing for the removal of garbage and obstructions that may contribute to flooding (DSD, 2017c).

The *Source-Pathway-Receptor* (SPR) approach adopted by PUB in Singapore covers the entire drainage system, addressing flood protection not just along drains (*Pathways*) through which stormwater is conveyed, but also in spaces generating runoff (*Source*) and spaces where floods can potentially occur (*Receptor*). Source solutions aim to reduce runoff from development sites into the public drainage system. For example, as legislated by PUB in their Code of Practice on Surface Water Drainage (PUB, 2013a), industrial, commercial, institutional and residential developments greater than or equal to 0.2 ha in size are required to control the peak runoff discharged from the development sites. As of 2014, developers of new or re-developed sites must implement on-site detention and/or retention measures to reduce peak runoff from developed areas into public drains by 25–35% (PUB, 2014). Pathway solutions typically includes traditional measures such as drain capacity improvements and diversion canal constructions, which will not be elaborated here.

Fig. 6. A car which was inundated in a flood at Bedok North district in Singapore on Jan 8, 2018 morning, after an intensive rainfall over many parts of Singapore. Source: (Twitter/SynCPositive, approved).

Finally, receptor solutions aim to protect infrastructures from floods and can be categorised as structural and non-structural. Examples of structural measures include raising platform levels of developments and crest levels to basements and underground facilities (PUB, 2013a). The SPR model that PUB (Singapore) has been adopted and legislated, which is successfully addressing the flood risk in the entire catchment and drainage areas with substantial analysed hydrological and other relevant information on the flood source (e.g. rainfall, wind, waves and tidal changes), pathways (e.g. overtopping, overflow, breaching, over-washing) and receptor (e.g. people and properties). Among other Asian coastal cities, Singapore has demonstrated that the SPR model is effectively helping water engineers, planners and decision makers for achieving better decisions on new developments, landuse changes and land drainage requirements. Whilst, enhancing the flexibility in engineering design to cope with the most effective scenarios and options for the structural measures matters, it is also crucial to undertake pathway and real option analysis that integrate with climate change adaptation policies (Buurman and Babovic, 2016), and help to improve project management strategies and the decision-making process (Zhang and Babovic, 2011). Non-structural measures include pre-emptive flood monitoring by subscribing to heavy rain alerts and updates on water levels in waterways are useful to enhance flood preparedness and reduce flood impacts which will detailed in the following section.

4.2.2. Enhancing flood preparedness

One aspect of the evolution of the FRM paradigm in Hong Kong and Singapore is the growing emphasis on non-structural methods such as boosting flood awareness and preparedness of the inhabitants, despite both governments have been financially invested in various (structural) flood protection measures, they have now adopted mixed approaches (combined structural and non-structural) to reduce flood risk. In Singapore, for instance, PUB has developed a free Short Message Service (SMS) alert service for locals who wish to monitor water levels in specific major waterways and/or receive notifications when heavy rain is expected (PUB, 2017), and send out flood alerts and warning via social media (Channel News Asia, 2018). Subscribers receive alerts if the water levels in the selected waterway rise above certain limits. Over 200 water level sensors have been installed across the country in key waterways. Meanwhile, the Meteorological Services of Singapore sends SMS notifications to alert subscribers of anticipated heavy storm events and the corresponding areas affected. Singapore has also worked substantially on the comprehensive assessment of extreme weather and monitoring flood (and drought) conditions in various seasons (Li et al., 2016; Ziegler et al., 2014).

The Hong Kong Observatory (HKO) provides the following to resident subscribers free of charge: (1) a rainstorm warning system (for three signals of amber; rainfall exceeds 30 mm/h; red; 50 mm/h; and black; 70 mm/h); and (2) real-time rainfall data, information of storms, typhoon, tides, storm surge alerts and release these real-time information by HKO internet webpage, mobile apps, radio and TV channels, as well as special announcement of flooding in the low-lying flood prone areas of the Northern New Territories (HKO, 2017d). Following the 2008 and 2009 coastal floods of Tai O town, the HKO and DSD established a special coastal flood warning system for the residents of Tai O. Whenever extreme weather conditions are predicted by the HKO, coastal flood alerts are triggered, and notifications broadcasted to subscribers (Chan et al., 2013b). Saito (2014) agreed that early flood warning systems are vitally important to Bangkok and Asian coastal cities to reduce social vulnerability from flood exposure in future. The Bangkok Metropolitan Administration (BMA) has also released real-time hydrological data (rainfall and water level) across over 70 flood detectors

and urban channel stations through the Thai Meteorological Department website, social media (e.g. Facebook and twitter) that similar to SG and HK (BMA, 2010).

In another effort to enhance preparedness, the Hong Kong government has begun to carry out emergency response drills in disaster prone areas. The annual drill on emergency response to flooding in the town of Tai O, initiated following the 2008 and 2009 coastal flood events (news.co.hk, 2011), is a multi-agency initiative involving various governmental departments including the Fire Services, Police Force, Home Affairs Bureau, DSD, and HKO, that allows representatives to familiarise themselves with the response plan and to practice evacuating residents during flood hazards (info.gov.hk, 2015). Activities during the drill include the evacuation exercises via planned escape routes, rescue plans, provision of emergency shelters, medical support, food and water supply.

The DSD established an Emergency and Storm Organisation that allows senior engineers to handle emergency issues, to coordinate the drainage levels and to clear blocked drains to ensure the performance of stormwater runoff and hydraulic structures and flood water pumping stations (DSD, 2017c). With real-time monitored data, the DSD can analyse flood situations and co-ordinate with other emergency service institutions to prepare for rescue, evacuation, and development of contingency response activities. In some frequently flooded villages (e.g. North New Territories), local flood warning systems have been installed to inform the villagers and local residents to take precautionary measures or escape when the river level reaches alert level (DSD, 2017d).

4.2.3. Meshing sustainability goals with flood management

The Hong Kong and Singapore authorities have also adopted green and environmentally friendly approaches to flood management. For example, to promote nature conservation, the DSD has incorporated various environmentally friendly concepts in recent drainage works: e.g., vegetating channel embankments to enhance aesthetic value and diversity of micro-habitats; using gabions and geo-fabric reinforced grass lining to stabilize side slopes instead of concrete walls; retaining meanders of rivers; using unlined embankments and channel beds to enable colonisation of flora and fauna (DSD, 2017a). One example of such endeavours by the DSD is the Ecological Enhancement Work of Yuen Long Bypass Floodway Project (DSD, 2017b). To compensate for the loss in ecological values, the DSD has converted a 70-ha piece of land adjacent into a wetland that also functions as a habitat for various wild life. Since its establishment at the end of 2005, a total of 118 species of birds have been recorded in the constructed wetlands. In addition, dragonflies (21 species), butterflies (30), amphibians (7) and reptiles (4) have also been recorded (DSD, 2017b).

The Singapore Government has also adopted a similar green and environmentally conscious approach, which is epitomised through the launching of the *Active, Beautiful, Clean (ABC) Waters* programme in 2006 by PUB. The ABC Waters programme is a strategic initiative to improve the quality of water and life by harnessing the full potential of waterbodies through the management of stormwater water using *low impact design* (LID) or Sustainable Urban Drainage Systems (SUDS) *water sensitive urban design* (WSUD) approaches (PUB, 2016a). In brief, the programme combines three key components (Lim and Lu, 2016): (1) the '*Active*' component aims to create new community spaces around water bodies; (2) the '*Beautiful*' component involves the enhancement of the aesthetical aspects of local waterways and water bodies; and (3) the '*Clean*' component endeavours to improve the quality of urban runoff.

Soft and green water features (e.g. swales, bio-retention systems, green roofs, constructed wetlands) are implemented to replace, complement or improve traditional (usually concrete-based) drainage infrastructures. The Kallang River-Bishan Park project, for example, highlights the principal ideas of the ABC Waters programme. The work entailed the restoration of the Kallang River from its channelised form as a 2.7-km concrete drain. Upon the completion of the 76 million SGD-project in 2012, a meandering, restored river with lush, vegetated floodplains now flows through Bishan Park in place of a straight, open-top concrete channel. As of March 2016, the development of over 30 ABC Waters sites have been completed with another 100 more potential locations identified for implementation by 2030 (PUB, 2016a) Further research studies have been undertaken on assessing economic impact of LID or SUDS practices (e.g. green roofs and porous pavements) in Singapore, such as assessing the value of a flexible extension in the design of urban water management systems based on SUDS to improve value for investment and help decision-makers to make better decisions towards achieving sustainability goals in FRM (Deng et al., 2013).

Among other Asian cities, such as Tokyo that has undoubtedly well proven the success of using advanced engineering techniques (e.g. channelisation, underground artificial channels and flood storage, etc.) for addressing the stormwater issues. But equally causing ecological impacts, such as removal river banks and beds to enhance habitat losses for freshwater organisms (fishes and invertebrates), and Tokyo now is also moving towards to adopt the LID techniques in stormwater management (Saraswat et al., 2016). HK and SG have been understood the ecological impacts from FRM progress previously from engineering structural measures, now they have taken on the steps ahead and promoting sustainability that have been initiated schemes to address the ecological habitats and delivering multiple benefits (e.g. Nature Based Solutions) in the urban environment.

5. International lessons

Certainly, the context of growth, developmental pressure and other social-economic factors (e.g. culture and politics) of Asian coastal cities are vastly different with other coastal cities in the world. However, all coastal cities are equally facing the climatic and meteorological effects (global sea-level rise, cyclonic monsoons, intensive rainstorms, etc.) as a common factor. This discussion is not intended learning from these global practices, but providing this opportunity to exchange FRM insights, experiences and lessons that may possibly be giving both sides to learn from each other that benefits coastal cities for undertaking better flood risk alleviation strategies for future. While both Hong Kong and Singapore have been able to mitigate flood hazards (mentioned in section 4), both encounter challenges that may be addressed by exploring evidence from other cities in the world. First of them concerns governance arrangements and the collaboration across the boundaries of sectoral departments of the city government (see Figs. 7 and 8).

London provides an example that the best way to avoid floods is to limit development in flood risk zones. City authorities have taken a proactive approach of adopted planning practices to restrict developments in the core city and the Greater London area via practices such as the UK's Planning Policy Statement (PPS) 25 (Department for Communities and Local Government, 2007) (namely National Plan and Policy Framework (NPPF) lately), which promotes flood risk mitigation integrated with spatial planning, to avoid new developments located in high flood risk zones. This planning practice also emphasises the appraisal of future flood risk including climate change projections to estimate the future hydrological changes and the potential flood risk regarding the planned urban development. On that basis, proposals for new developments in at-risk areas are restricted (Penning-Rowsell and Pardoe, 2012; Environment Agency, 2009; McLean and Watson, 2009).

This issue especially concerns Hong Kong, where the Planning Department lacks authority in dealing with fluvial and coastal flood risk issues, which are only taken under consideration as part of drainage ordinance. In Hong Kong, under the OZPs, the TPO and DIA focus on the surface water discharge on drainage systems which means planners are empowered to manage drainage issues of new developments, redevelopments and regeneration projects. These policies have undoubtedly reduced urban flood risk (or explicitly surface water flood risk) through development of a better drainage system under the Drainage Master Plan (see above). However, the OZPs lacks authorisation and power to restrict new developments on high flood risk areas (TPB, 2008). The DIA is unable to address coastal floods and coastal area developmental issues (DSD, 2010). Moreover, planners do little to restrict new developments in flood zones, especially in areas prone to storm surges where drainage systems will not be able to mitigate coastal flood risk. Alarmingly, the spatial plans for Hong Kong in 2030 perspective propose further ambitious expansion onto highly vulnerable reclaimed land.

Rotterdam has also promoted participation in the FRM decision-making processes through dialogues among the key stakeholders (flood managers, decision makers and the public). Water managers are required to provide advice on land use developments from the water and flood risk management perspective. The evaluation of water assessment for flood protection safety standard and reduction measures are required in new development plans (Woltjer and Al, 2007). The role of water managers is to co-ordinate and ensure participation through various stakeholders in FRM (i.e. planners, water engineers, government officials, developers and the public). There is a consensus that this approach will enhance co-ordination between different sectors and stakeholders (van Herk et al., 2011). The governance and institutional arrangements in the FRM should be more explicit, which will be helpful for identifying and arranging the specific roles and functions from all relevant stakeholders.

In general, public participation benefits from accessibility of transparent flood information. In the UK, for instance, flood risk mapping is freely available to the public via the Environment Agency website, for stakeholders to understand the risk of various types of floods (Environment Agency, 2014a, 2014b). The public is free to access the latest information on flood risk by the postal code, which effectively increases flood awareness, preparedness, and resilience (Lo and Chan, 2017). More generally, the role of public participation is increasingly recognised in flood governance to improve preparedness and awareness. The coastal flood contingency drill in Tai O town in Hong Kong implemented with close engagement of local communities (Chan et al., 2013b), again is an excellent example. The Short Message Service (SMS) alert service by more than 200 sensors along the city that developed by PUB has also largely increased the flood awareness in Singapore. Most of Asian coastal cities should be considered this option which is effectively increasing the effectiveness of flood preparedness.

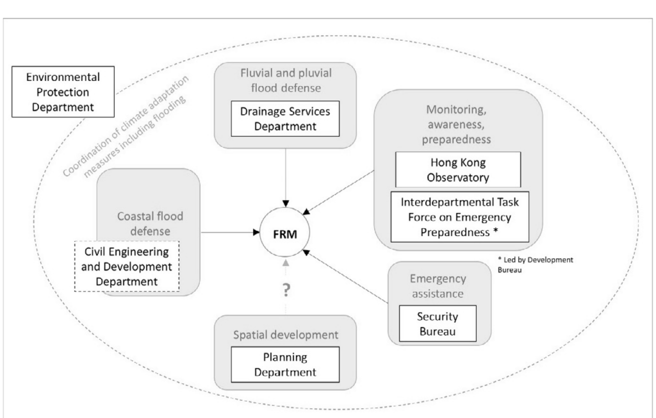

Fig. 7. The flood risk management governance structure of Hong Kong. Source (Marcin Dabrowski).

In New York City (NYC), Rosenzweig and Solecki (2014) suggested the government has been proactively engaged with improving the contingency plan that includes ensuring wider flood insurance coverage for residences within 1-in-100-year flood zones, improving the utilities and energy supplies and guaranteeing adequate food supplies in the extreme condition. Currently, in the region of greater China and Asia Pacific, flood insurance is not popular or not available in many Asian cities. For example, landowners and property owners require to purchase property insurance that only covers the floods from seepages, pipes leakages and drainage problems, but not from rivers and coastal flooding in Hong Kong (Lamond et al., 2017). The government policy has not been supportive to private insurers for promoting this service (due to lack of accurate flood risk information) or the private insurers projected the risk for some areas are too high to offer any flood premium packages (Lamond et al., 2017; Lamond and Penning-Rowsell, 2014). In the future, flood insurance system should be widely introduced as currently it is only the combined home/property insurance package available in the market by private insurers, which will be another option to reduce economic risk after floods, especially on improving flood recovery process (Swiss Re, 2014; Chan et al., 2013a).

6. Knowledge transfer to other Asian cities

An important question for the region is whether the lessons learned in Hong Kong and Singapore are useful examples for other Asian coastal metropolises—many of which are the most vulnerable in the world to flood risk and will likely remain so without significant flood mitigation advances. The analysis of future flood losses in major coastal cities by Hallegatte et al. (2013) determined that 10 of the 20 cities with average annual losses (AAL) were Asian port cities (in order of risk): Guangzhou, Mumbai, Nagoya, Shenzhen, Osaka-Kobe, Tianjin, Ho Chi Minh city, Kolkata, Fukuoka-Kitakyushu, and Jakarta. They point to Ho Chih Minh City, which has a relatively low 100-year exposure ($18 billion), but because of limited protection, recurrent floods elevate annual losses. In terms of relative risk, average annual losses were an estimated 0.74% of the local GDP, placing it only behind Guangzhou (1.32%) in relative risk for Asian coastal cities. By 2050, considering sea level rise and subsidence, 14 of the 20 cites with the highest estimated flood losses are projected to be Asian coastal cities: Guangzhou, Mumbai, Kolkata, Shenzhen, Tianjin, Ho Chi Minh City, Jakarta, Chennai, Zhanjiang, Bangkok, Xiamen, and Nagoya (Hallegatte et al., 2013).

Following recent major floods in the last decade, many Asian cities have begun to invest heavily in flood protection measures. Problematic for knowledge transfer (e.g. from Hong Kong or Singapore), however, is the uniqueness of any given city with respect to geographical setting, socio-economic status, and political situation. Unlike Hong Kong and Singapore, many of these at-risk cities are also currently subjected to significant subsidence, which increases sea level relative to mean height of the urban centres. Further, governments tend to respond to flood disasters by fixing drainage problems to achieve immediate relief, rather than addressing the miasma of issues that are often at the heart of flood vulnerability—and will likely persist in the long run.

Jakarta is an example of a city struggling to keep up with recurrent floods in 2002, 2007 and 2013 (Budiyono et al., 2015). Uncontrolled development in the city has led not only to floods, but several urban planning issues, such as traffic congestion, poverty

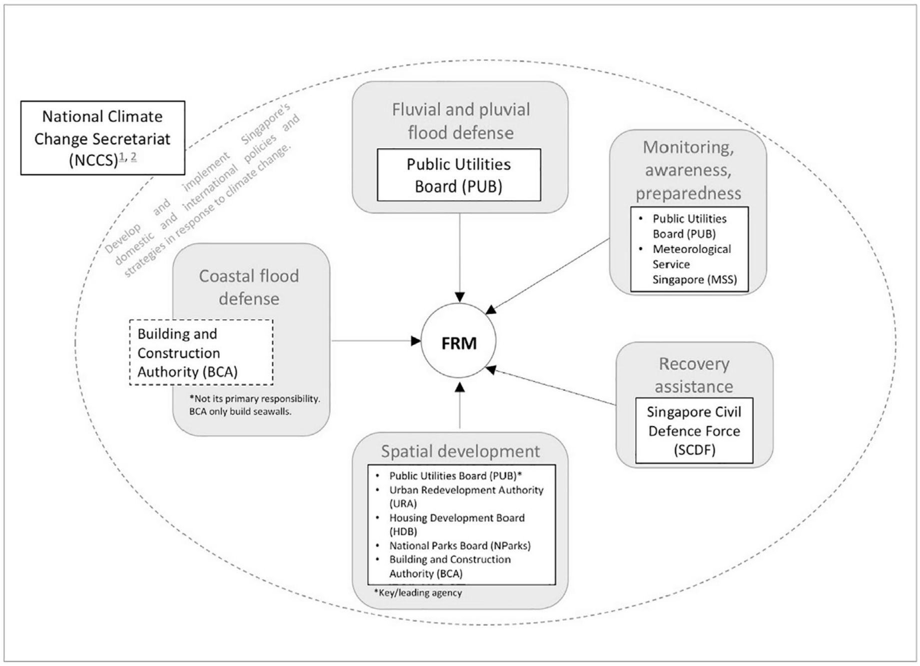

Fig. 8. The flood risk management governance structure of Singapore. Source (Marcin Dabrowski and Chuah Chong Joon).

and inequality (Human Cities Coalition, 2017). Flood threat stems from several rivers feeding into areas of the city that lay below sea level (mean annual subsidence 5–10 cm). However, floods are likely exacerbated because many channels are clogged with waste, high levels of river sedimentation, and seawater over-flowing retention structures. The city has also been suffered from urban pluvial and fluvial floods because of rapid urbanisations and city expansions, but lack of adequate stormwater water drainage system that unlike Hong Kong and Singapore with sufficient land drainage facilities (e.g. Drainage Master Plans in Hong Kong, and Code of Practice on Surface Water Drainage in Singapore). Moreover, the natural water bodies, such as lakes, wetlands, and waterways which can take on substantial amount of urban stormwater, have been reduced or filled, therefore increasing the incidence of floods (Ward et al., 2011a). Lately, the city established a Comprehensive Flood Management Plan that recognised higher risk from population growth, land subsidence, insufficient drainage system maintenance, and a reduced flood return period (Jha et al., 2012). The government has issued various policies, including the normalization of 13 rivers and the construction of the Giant Sea Wall in an effort to prevent future flooding. Normalizing involves widening channels and building concrete embankments and barriers to keep residents from living in these areas (Human Cities Coalition, 2017). Further, the Jakarta Coastal Defense Strategy (JCDS) was implemented in 2014 to improve coastal land-use planning and urban resilience (Hidayatno et al., 2017). However, Ward et al. (2011b) estimated damage exposure to large flood events (from 1-in-100 to 1000 years return periods) are high (up to £ 5 billion) in Jakarta, the damage projected to be more severe with climate change alongside with the land subsidence in future, suggested that is not financial sensibly protecting all coastal communities by structural measures (e.g. seawall), and the municipal government should adopt climate adaptations and non-structural approaches. Similarly, Mishra et al. (2017) suggested Jakarta should focus further on enhancing non-structural approaches in FRM, such as integrate the flood risk assessment with landuse planning, and projecting climate change (e.g. hydrological patterns and changes) with the Global Climate Models and future urbanization scenarios, these tools and information will be effectively helping policy makers, water managers and local planners to achieve better flood management. Marfai et al. (2015) also urged the municipal government to improve flood forecast and warning systems which is essentially reducing flood hazards for communities in Jakarta. Scholars lately purposed these practices are eventually towards the FRM directions that Hong Kong and Singapore have been undertaken on non-structural approaches (flood warning system; Planning practices: DIA and OZP in Hong Kong; SPR model in Code of Practice on Surface Water Drainage in Singapore, etc.), which will be sustainably reducing future flood impacts with the common challenges that in line with other Asian Coastal cities are facing (e.g. climate change, rapid growth of coastal population, urbanisations, etc.). In Bangkok, the 2011 Chao Phraya River Flood in Bangkok was caused by factors including an unusually heavy monsoon, building on flood plains and changes in water management - affected millions of people and caused $45.7 billion (1.43 trillion Thai Baht) in losses (Ziegler et al., 2012a,b). In response to expected continued urbanization and extreme weather linked to climate change, the BMA introduced several flood protection projects worth nearly 26 billion baht ($765.6 million), including dredging and expanding canals, and constructing flood barriers and water retention areas to drain and divert floodwater to Thailand's main conduit, the Chao Phraya River (Thin Lei Win, 2017). The Thai Government aimed to improve the flood protection level up to 1-in-100 years return period in Bangkok (similar with the scale as the 2011 Chao Phraya River flood) after the 2011 flood (World Bank, 2012), the city also issued a resilience strategy that includes improved weather forecasts and drainage systems. However, because of funding constraints, the city has not been fully implemented the Drainage Master Plans across all flood prone districts, and some urban drainage protection level is still at 1-in-2 years return period, which is not enough to withstand of frequent intensive rainstorms (Saito, 2014). Lately, the BMA has also followed HK and SG and adopting sustainable FRM and LIDs approaches such as vegetation swale, bioretention tanks, vegetative strips along roads, artificial ponds and permeable pavements (BMA,

2013). The BMA realised these practices are the "win-win" strategies to reduce urban flood risk by increasing stormwater storage and minimising the pressure of urban drainage during the rainstorms, but also delivering ecosystem services in urban environment, such as increasing blue-green areas for recreational activities, wildlife (e.g. birds, bees, butterflies, fishes, etc.), and improving air quality, reducing carbon emission, etc., which has been implemented in the urban districts at Bangkok, and should be encouraged promoting to other Asian coastal cities (Saraswat et al., 2016).

In this paper we have highlighted the advances of flood governance in Singapore and Hong Kong, yet we must keep in mind that the effective FRM approaches implemented in each were first applied long after substantial infrastructure investments were made to mitigate large floods that were recurrent in the past. Encouraging in the Jakarta, Bangkok and other Asian coastal cities is the recognition to go beyond solely building flood control structures—although engineering-based flood control is still at the heart of flood governance in both cases. Only time will tell regarding the success of implemented FRM practises. Nevertheless, we encourage other governments to (continue to) include these and emerging approaches (e.g. green and sustainable practices) early as they implement traditional hard-engineering flood control structures.

Critical for Asian coastal cities in the future is controlling urban development, improving the understanding of all facets of flood governance, bracing for the likelihood that the projected climate change impacts will be real, and fostering strong inter-agency collaborations. In general, institutions dealing with the issues of flood risk and climate adaptations often find difficulty in collaborating with other sectoral policies and institutions. Lack of cross-sectoral collaboration (which, by the way, affects most governments) may also be caused by silo-mentality and segregation between the departments of the government (Francesch-Huidobro et al., 2017).

Also, important thing that needs to address in this paper, which is HK and SG are still some rooms improving the current FRM practices despite they both have been achieved good practices as mentioned. One of the issue that is resolving jurisdictional ambiguities, for example, in the management of inland versus coastal floods. In Singapore, the Building and Construction Authority is tasked with safeguarding Singapore's long-term coastal protection needs, but coastal flood protection is not a responsibility (NCCS, 2016). The issue of flood control typically lies in the remit of the Public Utilities Board. In the case of Hong Kong, the DSD is responsible for the management inland floods (related to river channels and drainage systems) and coastal floods that occur as a result of sea water backlash in drainages. However, it is unclear which department(s) is/are accountable for coastal flooding.

In Hong Kong, the Civil Engineering and Development Department is responsible for the technical design and construction of coastal protection infrastructure (e.g. sea walls and breakwaters), but not managing flood events associated with sea-level risk. For example, during the recent coastal flood in August by Typhoon Hato that flooded some residential areas in Hong Kong Island and other low-lying areas (e.g. Tai O town) (Weather.com, 2017), the CEDD had no authority and responsibility. The Planning Department has no obvious roles in addressing flood risk other than liaise with the DSD on drainage impact assessment in new planning project/development appraisals. The issue of climate change is under the consideration of the Environmental Protection Department, which has no formal duties concerning flood protection.

Such ambiguity in any locale necessitates that roles of responsibility should be clarified to improve flood governance. Close cooperation between agencies such as DSD/PUB and other planning-related entities should allow for land and spaces beyond jurisdictions to be fitted with flood risk reduction measures, for example, by embedding them in the planning and development of future projects spearheaded by other agencies. As a well-considered approach in flood management that involves cross-departmental cooperation is likely to be effective and beneficial, there is a need to formulate a comprehensive and integrated strategy that would engage the various departments in a concerted manner, with clearly defined roles for FRM.

7. Conclusion

Asian coastal cities will likely become more vulnerable to the emerging climate risks because of an increase in storm frequency and size, combined with unregulated development (IPCC, 2013). Hong Kong and Singapore have joined the C40 Cities network (C40, 2017) to engage with other cities in efforts to address the potential climate risks and impacts (Hong Kong as a steering committee; and Singapore as an observer city). Both cities have already achieved a fairly high standard of flood governance, and both are actively engaged with further improving climate adaptations and resilience practices. Nevertheless, it will be a challenge to limit flood impacts as both expand and/or grow economically.

Across the region, most coastal megacities are not equipped with adequate governance schemes to handle changes that are likely associated with climate change and urbanization (Varis, 2006). Moving forward, governments should adopt proactive means of integrating FRM and climate adaptation approaches into spatial planning policies, alongside traditional flood-control practices that provide short-term solutions. They should also work to resolve jurisdictional ambiguities and strive for strong inter-agency collaborations to ensure sound flood governance. Future research could explore ideas on how to best operationalise lessons learned in the Hong Kong, Singapore, as well as other international cities, to facilitate knowledge transfer to other coastal metropolises that are projected to be vulnerable to flooding in the future.

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